

Northumbria Research Link

Citation: Pearsall, Nicola, Atanasiu, Bogdan and Zdanowicz, Tadeusz (2008) Progress on the modernisation of the European PV system monitoring guidelines. In: 23rd European Photovoltaic Solar Energy Conference, 1-5 September 2008, Valencia, Spain.

URL:

This version was downloaded from Northumbria Research Link:
<http://nrl.northumbria.ac.uk/id/eprint/6473/>

Northumbria University has developed Northumbria Research Link (NRL) to enable users to access the University's research output. Copyright © and moral rights for items on NRL are retained by the individual author(s) and/or other copyright owners. Single copies of full items can be reproduced, displayed or performed, and given to third parties in any format or medium for personal research or study, educational, or not-for-profit purposes without prior permission or charge, provided the authors, title and full bibliographic details are given, as well as a hyperlink and/or URL to the original metadata page. The content must not be changed in any way. Full items must not be sold commercially in any format or medium without formal permission of the copyright holder. The full policy is available online: <http://nrl.northumbria.ac.uk/policies.html>

This document may differ from the final, published version of the research and has been made available online in accordance with publisher policies. To read and/or cite from the published version of the research, please visit the publisher's website (a subscription may be required.)



**Northumbria
University**
NEWCASTLE



UniversityLibrary

PROGRESS ON THE MODERNISATION OF THE EUROPEAN PV SYSTEM MONITORING GUIDELINES

N. M. Pearsall¹, B. Atanasiu² and T. Zdanowicz³

¹Northumbria Photovoltaics Applications Centre, Northumbria University, Newcastle upon Tyne, UK

²European Commission Joint Research Centre, Institute for Energy, Ispra, Italy

³University of Wrocław, Poland

ABSTRACT: In the context of a rapid development of the PV market, both in terms of capacity and the type of applications, the EC-funded Integrated Project PERFORMANCE is developing a modernised set of guidelines for the monitoring of PV system performance. The completed guidelines will be easily accessible for all interested parties, from system designers to system users and/or financiers, and will provide guidance on both the measurement of PV systems and the analysis of their performance. This paper discusses progress on the development of the web-based guidelines package, including the approach to allow custom guidelines to be generated for a wide range of users, the development of a failure modes effects analysis tailored to the monitoring process and the opportunity for industry input to the final development phase.

Keywords: Monitoring, PV System, Performance

1 INTRODUCTION

The rapid development of the PV market, in terms of capacity, types of application and range of market players, has led to the requirement for an expanded range of monitoring protocols and services to meet the different market needs. Advances in the industry have outstripped the available standards and guidelines for the measurement and assessment of system performance. In this context, the EC-funded Integrated Project PERFORMANCE [1] is developing a modernised set of guidelines for the monitoring of PV system performance. The completed guidelines will be easily accessible for all interested parties, from system designers to system users and/or financiers. The objectives are:

- To provide a tool for decision making in regard to the level and complexity of monitoring for different system types
- To validate the best practices currently in use by the industry and use these as the basis for the modernised guidelines
- To develop new guidelines where insufficient guidance exists
- To enable both existing companies and those entering the PV market to provide suitable monitoring services consistent with the expectations of the system user.

The paper will describe the approach to modernising the guidelines to achieve these objectives and discuss the progress to date and the programme for completion and implementation.

2 PV SYSTEM MONITORING REQUIREMENTS AND PRACTICES

There has been rapid growth in the PV market over the last decade with an estimated cumulative installed capacity of 9 GWp globally by the end of 2007, around half of that installed in Europe [2]. The applications range from small (a few 100W) to large (several tens of MW) and from domestic systems, either grid connected or stand alone, to power stations installed as part of utility or private investment initiatives.

Whilst different users operate their systems under

different technical and fiscal conditions, they all have a requirement for high performance throughout the lifetime of the system and a need to identify system losses (due to operational issues or faults) within a timescale appropriate to the economic losses associated with reduced output. Whilst fault identification may be more urgent for a large system operating under a feed-in tariff where the loss of output has severe financial consequences, it is nevertheless important that the small user also has the opportunity to identify and rectify losses. It is worth noting that it is not only faulty or substandard equipment or design that causes problems, but that substantial losses can be incurred due to operational issues such as shading or problems with grid connection that may arise or worsen during the course of system operation. To put it simply, systems operating below a reasonable standard are a wasted opportunity in terms of energy contribution. Losses directly impact the economic viability of the system and users who feel that they are not getting the output promised are understandably poor ambassadors for the promotion of the technology.

The PV industry has developed a number of approaches to provide the monitoring services required in an expanding market. These include:

- Monitoring services for large installations included within a maintenance package and offering fault identification and rectification within a defined period (offered by many of the major installers – e.g. the maintenance and monitoring services offered by Phoenix Solar AG and Conergy);
- Monitoring systems including analysis software specifically designed for PV systems, for purchase from specialist companies or as part of the inverter package;
- Comparison web sites where owners of small systems can check their output against similar systems in the same area;
- Monitoring services for small systems based on satellite-derived irradiation data, in some cases including automatic fault detection (e.g. commercial services based on the results of the PVSAT-2 project [3]).

These commercially available systems and services have been developed in response to customer need, but

the procedures and quality are not underpinned by standards or guidelines that reflect the developments of the market place or the monitoring services themselves.

System monitoring designed to identify faults and their causes and thereby minimise output losses can be generally likened to insurance. The more extensive the package, and thus the more costly to implement, the faster faults should be able to be recognized and the lower should be the overall loss of output. However, small system users often do not have the experience of PV or other similar systems that would let them make a rational decision about the level of “insurance” to choose with respect to the monitoring services on offer. The guidelines will also provide information on the level of detection that can be obtained for different levels of monitoring to inform customer decisions. Clearly there also needs to be some consideration of the likelihood of loss, as well as the ability to detect that loss, and this is discussed further later in this paper.

Since the guidelines update needs to reflect best practice in the existing monitoring services offered by the industry as well as being a generic technical reference for new entrants to the market place, the development includes strong consultation with industry over the implementation phase, as described later.

3 THE IMPLEMENTATION OF THE MONITORING GUIDELINES

The overall concept of the updated guidelines was presented at the European Photovoltaic Solar Energy Conference in Milan in 2007 [4] and the work has now progressed to the implementation of the guidelines in their web-based format. The initial implementation has been designed to establish functionality and suitability of the approach to meet the requirements described above and has included consultation with a number of experts external to the project. This phase will result in the preparation of a more extensive version that can be assessed in depth by the PV industry early in 2009, so as to ensure that it meets their needs in terms of monitoring

guidance.

The first version of the guidelines has been implemented in Excel to allow ease of consultation and development, but no decision has yet been made on the final software platform to be used. In the first instance, it is necessary to have an open and easily accessible implementation so as to be able to ensure that all interested parties can input to the composition of the guidelines. For the final version, the functionality and ease of updating are key attributes.

As described previously [4], the different aspects of the monitoring and analysis procedure have been divided into “blocks” that deal with different aspects of the system (e.g. PV array, inverter), relate to specific groups of parameters (e.g. climate measurement) or relate to specific system types (e.g. concentrator systems). Within each block, there is a series of statements or axioms that provide detail of, for example, the parameter to be measured, the method and accuracy of measurement, the frequency of measurement etc. The axioms differ depending on the nature of the system and the requirements of the monitoring, as discussed in the previous section. A monitoring package is then constructed using selected axioms from relevant technical blocks, as illustrated in Figure 1.

A set of key questions is used to establish the system configuration and application. The responses to these questions are used to select the appropriate statements in each case to construct the most suitable monitoring and analysis package for the user and application. In this way, the guidelines can accommodate a variety of monitoring approaches within the same tool, ranging from what was previously referred to as global monitoring (manual recording of a small set of parameters) to detailed analytical monitoring [see reference 5 for further details of these monitoring definitions]. Indeed, consideration is also being given to what we term “minimum monitoring” for small, stand alone systems where even the global monitoring approach would be too onerous or expensive for the user. Figure 2 shows the first part of the user questionnaire as an example.

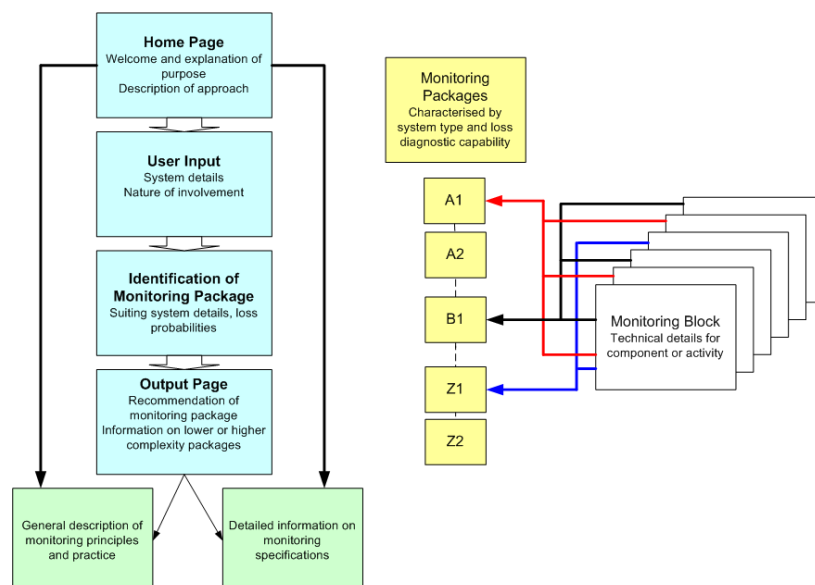



Figure 1. Schematic diagram of delivery concept as defined at the commencement of the implementation phase.




PERFORMANCE

MONITORING GUIDELINES

FOR

PHOTOVOLTAIC SYSTEMS




PLANT/SYSTEM NAME: _____

MONITORING DATE: _____

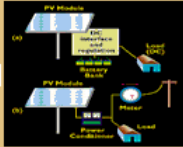
LOCATION: _____

Answer to the questions in order to produce the guidelines

GENERAL QUESTIONS




- 1 What is your interest area relating to this photovoltaic system?
- 2 What operational losses, exceeding those of the as-designed system, do you consider acceptable?
- 3 What is the size of the system?
- 4 Do you want to monitor only the general parameters of the system or a more detailed, analytical, monitoring?
- 5 What type of photovoltaic system do you wish to monitor?



COMMENTS: *For system with peak power over 5kW analytical monitoring is strongly recommended*

PV ARRAY



- 6 What is the structure of your PV generator?
- 6a

Figure 2. Screen capture from the user questionnaire page of the monitoring guidelines.

The construction of the guidelines is simple and functional. Each axiom in each technical block is assigned a predefined number through which it can be identified. The answers to the key questions are also assigned numbers that cross-reference directly to the numbered axioms. Where necessary, sub-questions are provided to refine the answer and define the specific monitoring requirements. Axioms in different technical blocks can have the same number assigned, provided that they apply to the same type and application of system and so are called correctly. Assuming that the Guidelines are a concatenation of axioms, the string of numbers produced as a consequence of the responses to the user questions is a unique way to identify the monitoring frame and the user profile. A brief example of how this system functions is given opposite.

Let us now consider how this leads to the guidelines production with a further example. One of the most important measurements for determining system losses is that of the solar irradiation falling on the array. Knowledge of the irradiation level allows system yield over a given period to be compared with expected values and the system efficiency to be calculated. Consideration of the way output varies as a function of irradiance level can identify losses due to operation thresholds, incorrect sizing of the inverters or, in some cases, temperature effects. Comparison of the shape of the output profile with that of the irradiance profile can identify losses due to shading or inverter outages. The accuracy of measurement of the irradiance level has a direct influence on the level of loss that can be identified and on the ability to determine the cause of that loss.

Example: In the following example, which considers question number five in the current guidelines, two different possible answers exist depending on the nature of the system.

5 Which type of photovoltaic system do you want to monitor?

Each answer has a corresponding number:

- Grid-connected, number 2
- Stand-alone, number 3
- Blank space, number 1

Note: The blank space is included for initialisation of each question when the user first accesses the guidelines. Leaving the answer blank will result in an error message reminding the user to complete all questions before the guidelines can be displayed.

Reporting each question with the relative number according to the answer, the "DNA" string will be then produced.

1	2	3	4	5	6	6a	7	7a	5	=question number
3	2	3	2	3	4	2	2	6	3	=answer number

The complete questionnaire string is compared with the pre-defined code of axioms. Specific monitoring guidelines can then be produced depending on this "DNA" axioms selection.

Existing guidelines [5, 6] describe the measurement of irradiance in the plane of the array and generally require this to be done on-site by a reference cell (calibrated in accordance with IEC 60904-2 or 60904-6 as appropriate) or a pyranometer. The EC guidelines [5] stress the importance of aligning the reference cell precisely with the plane of the array. Clearly, a suitably calibrated, correctly aligned and well maintained irradiance sensor mounted close to the PV array in an unshaded position gives the greatest accuracy of measurement and thus the highest possibility of loss determination. However, the expense of purchase, installation and maintenance may be prohibitive for small systems (based on the comparison with the expected value of any losses) and a poorly maintained sensor on site may be of less use than a correctly maintained sensor elsewhere.

Various other options exist. In some cases, where multiple systems are installed on a single site (e.g. a housing estate), it may be possible to install a central sensor that can be used for all of the systems and also maintained centrally, provided that there is not too much variation in array orientation. Alternatively, a sensor on another site or a central measurement service can be used. In this case, the measurement is usually for the horizontal plane and some errors are incurred by the translation of the value to the array plane. Finally, it is now possible to obtain irradiation values derived from satellite data, again for the horizontal plane.

Studies of the accuracy of satellite data compared to ground based measurements for the USA indicate that the uncertainty of the satellite data is lower than that for ground based sensors once the distance to the ground based measurement is in the 20-50 km range (depending on the frequency of measurement) [7]. Clearly, this will depend on the location, since it will vary with climate, but gives an indication of the distance at which it would become more favourable to consider satellite derived data from an appropriate source. Nevertheless, the higher uncertainty of satellite data compared to on-site measurements means that larger percentage losses will be incurred before the existence of the fault is identified, typically around 17% in summer months and higher in winter months [3].

The guidelines must reflect all these issues without being too complex and whilst providing clear guidance. Thus, each section will start with a series of generic statements describing the measurement in question and common to all packages. They will then provide information on the specific recommendation (or a choice of options only if this is appropriate). However, the user will have the possibility of viewing other monitoring options if they wish to consider other approaches. Table 1 gives an example of the statements for the irradiation measurement issues discussed above, concentrating only on measurements on-site for individual arrays, off-site measurements from meteorological stations and satellite derived data. It should be noted that these are not necessarily the final versions of the wording since the industry consultation has not yet been completed, but they are indicative of the approach.

The recommendations will be selected according to system type and size and economic factors relating to the

value of the electricity generated. Whilst the above table considers only the initial statements for one of the measurements, consistency will be ensured across all technical blocks so that the desired accuracy of measurement and analysis is maintained.

4 PERFORMANCE ANALYSIS

Clearly, it is not sufficient to simply measure the performance data, but guidance must also be provided in relation to the analysis of those data to allow identification of the existence of an unacceptable loss and investigation of the cause of that loss. The current guidelines [6, 8] describe the determination of the main performance indicators of the PV array, including:

- Array and system efficiencies
- Capture and system losses
- Array, reference and final yields
- Performance ratio
- Monitoring and outage fractions
- PV energy contribution in the form of array fraction

They also provide some suggestions as to how to display these quantities graphically. However, they do not provide any guidance as to what these values should be numerically, how to identify when losses are higher than they should be and how to use the monitoring data to identify the causes.

The updated guidelines will include a much expanded information set in regard to analysis, again separated into statements that relate directly to the nature of the system and the data measurement already recommended. Guidance will also be given on how to check the data for consistency and errors in advance of analysis, so as to aid the interpretation of the indicators obtained.

Current monitoring systems have fewer constraints on the amount and frequency of data measurement than when the existing standards were written, due to the rapid development of low cost memory for data storage. Whilst it is not often cost effective to analyse data at short time intervals as a matter of course, interrogating these data when a fault or loss is observed can speed up the identification of the cause and thus the elimination of that fault or loss.

We can illustrate the effect of measurement frequency with a simple example. Figure 3 shows two graphs based on the same measurement data taken for a June day for a 2.2kWp domestic PV system in the UK. This system has two identical sub-arrays each connected to its own inverter. The irradiance in the plane of the array and the AC output power of the PV system were measured at one minute intervals. In the top graph, these data have been used to produce hourly averages of the two parameters and the resulting plot shows approximate agreement between the irradiance and the power output with no specific indication of problems. However, plotting the 1-minute measurements, as in the lower graph, clearly shows periods when both inverters were off during the day and close inspection reveals times when only one inverter is operating. In this particular case, the cause was high grid voltage rather than an inverter fault.

Table 1. Example of statement construction for irradiance measurement. Statements with an ID number of 0 will be included in all monitoring packages. Statements with other ID numbers will be called as required depending on the responses to the user questions. For space reasons, only some of the statements included in the description of irradiance measurement are given in the table below and some of the explanatory details are omitted. (Note that the ID numbers shown here do not relate to the possible answers to the question given in the example box earlier.)

ID No.	Statement
0	Irradiance data representative of the values in the plane of the array are required for use in the performance analysis of the PV system. If these are not available, it will restrict the possibilities for identification of losses and their cause.
0	Horizontal data may also be recorded to permit comparisons with standard meteorological data from other locations. <i>(see note (a) below)</i>
0	The in plane irradiance may be (a) measured on site, (b) measured at another site chosen to be representative or (c) derived from remote measurements (e.g. from satellite data), depending on precision requirements
0	An on-site measurement will provide the highest level of precision, provided that appropriate calibration, installation and maintenance procedures have been carried out.
1	Irradiance measurements, whether on or off site, should be made using a calibrated reference device or pyranometer.
1	If used, reference devices shall be calibrated and maintained in accordance with IEC 60904-2 or IEC 60904-6 as appropriate and, where possible, should be spectrally matched to the monitored PV array.
1	The accuracy of the irradiance sensors, including signal conditioning, shall be better than 5% of the reading and the temporal stability shall be better than 0.5% per year.
2	For on-site measurements, the sensor should be mounted so that the detector surface is in the same plane as the array and at a location representative of the irradiance conditions of the array. The sensor should be positioned where it is unshaded at all times (regardless of whether the PV array is partially shaded at any time) and in a location where it can be accessed for cleaning at the required intervals.
2	Where the PV array consists of more than one sub-array of differing orientation, sensors shall be located in-plane with each sub-array.
3	The reference site should be chosen to be representative of the PV system site in terms of location and climate <i>(this aspect still to be fully defined including the definition of the maximum distance between sites)</i> .
3	It is likely that reference site measurements will be for the horizontal plane. For all measurements not in the plane of the array of the system under consideration, an approved method of translation to in-plane values must be used <i>(details to be defined)</i> .
4	Where available, satellite-derived solar data may be used to infer the irradiation received by the PV array. This approach is most suited to small PV systems where the expense or technical aspects of on-site measurement cannot be justified. The precision with which losses can be identified will be lower than for on-site measurements correctly performed and may be lower than for off-site ground-based measurements depending on the distance between the measurement and system sites.
4	The satellite-derived data should be obtained from a recognised and named source, where one of the satellite functions is specifically to return solar data to the required accuracy <i>(details to be agreed with current data providers)</i> .
4	Since satellite derived measurements will be for the horizontal plane, an approved method of translation to in-plane values must be used <i>(details to be defined)</i> .

Notes to Table 1:

- (a) Horizontal measurements may also be used to verify the method of translation to an inclined surface in appropriate circumstances.

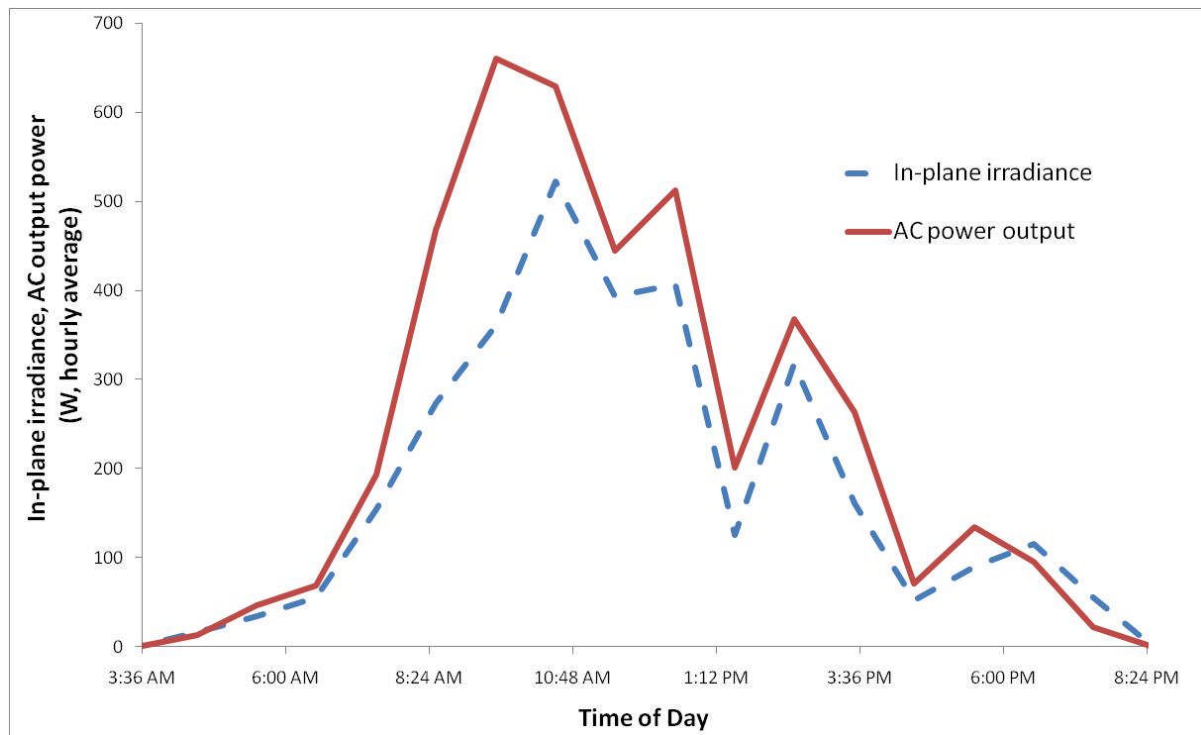


Figure 3(a). Comparison of AC power output and irradiance in the plane of the array for a 2.2 kWp domestic PV system in the UK on a June day. The curves are based on hourly averages of data measured at one minute intervals.

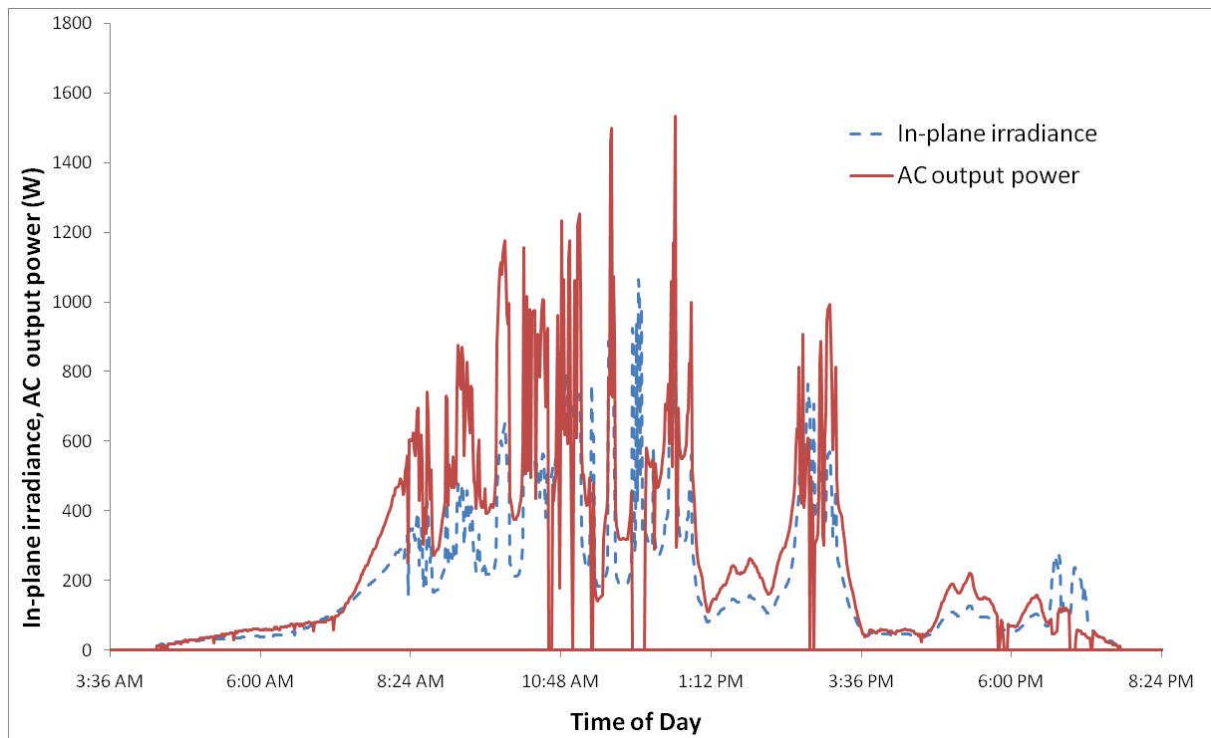


Figure 3(b). Comparison of AC power output and irradiance in the plane of the array for the same system as in Fig. 3(a) and for the same day. The curves are based on the data measured at one minute intervals.

Recording and displaying the frequent measurement data allows a rapid identification of an operational problem and some information on the likely cause, although this has to be balanced against the time taken to inspect the graphs. The guidelines will consider how frequently to measure and store data, how to display the data on a routine basis so that it demonstrates any major faults on the system and what additional analysis might be possible using the stored data.

One of the most powerful approaches for identifying losses is direct comparison of similar systems on adjacent sites or sub-systems in a large installation. The guidelines will make recommendations for the way in which this approach could be implemented where appropriate, for example, the number of sub-systems to be monitored and the parameters to be measured.

Direct comparison of measured parameters on the same system but at different times (of day or season) can also be used to determine losses, particularly due to shading or temperature effects. Again, guidance will be given as to what should be compared, at what intervals and how to interpret the results.

5 ESTABLISHING PROBABILITY OF LOSS

The determination of the most appropriate monitoring package depends on the value of the electricity produced and the probability that output losses will be incurred, in just the same way that the choice of the level of, say, house contents insurance, depends on the value of those contents and the probability that they will be lost or damaged. The determination of the probability of loss is perhaps the most challenging part of this project since the field data to support the determination are not readily available in the open literature (and perhaps may not be available in a usable form even within the industry).

The approach taken has been to commence a Failure Modes Effects Analysis (FMEA) at the system level with specific reference to the ability of the monitoring and analysis process to reduce the overall loss due to any specified failure mode (where the term failure includes reduced output as well as system breakdown). FMEA is a structured approach to identifying failure modes and estimating their associated risk and is commonly used in process industries for minimising risk and improving product yields. In this case, the aim of the FMEA is to provide a detailed consideration of individual failure modes and to assess the relative importance of each mode. The modes with the highest potential loss should be addressed first and less important modes only included where costs allow.

Three numerical indices are used to generate a Risk Priority Number (RPN). These relate to:

- Severity – the magnitude of the loss if this failure mode occurs
- Occurrence – the likelihood that this mode will occur in a specified period

- Monitoring – the effectiveness of the monitoring and analysis in detecting and diagnosing the cause of the performance loss

Clearly, the first two indices have high values for serious and commonly occurring failure modes, whilst the monitoring index is a low value for successful identification and diagnosis. In the first version of the FMEA, the monitoring index is determined from two sub-indices, one relating to whether the monitoring can identify that a fault exists and the other relating to how easily the cause of that fault can be determined from the monitored data. For example, most monitoring schemes can determine low system output, but not all causes can be identified from a small number of parameters or from values aggregated over long periods. Thus, the determination of the existence of a fault does not necessarily mean that the cause can be determined.

The first version assumes that the indices are all of equal weighting and are assigned values between 5 and 100. Note that zero values would result in a RPN value of zero which is meaningless in the context of the FMEA. Any failure mode scoring zero for severity has, by implication, no effect on system output. Any mode scoring zero for occurrence is hypothetical only (i.e. does not occur in practice). The project team believe that it is not useful to attempt to quantify the index to an accuracy of more than 5 (i.e. values of 5, 10, 15 etc.) and even this may imply an accuracy that is not possible in practice.

The occurrence can be linked to the percentage probability of occurrence in a specified period (nominally the system lifetime, but modified for failure modes associated with the end of life of components). The severity can be linked to the percentage loss of output arising from an undetected fault and the severity index can be determined by a technical consideration of the system (e.g. in relation to component failure) or by field experience (e.g. shading effects). The monitoring index can be determined from direct consideration of the monitoring and analysis possibilities of any specified monitoring package.

Table 2 shows a simple example of an FMEA entry for one possible fault, the failure of a component in the inverter that leads to inverter shutdown for a grid connected PV system. Only selected columns have been included for clarity. The full FMEA also considers interaction between fault mechanisms and some other descriptive information. The indices presented are for illustration only and are not expected to be the final values assigned. Only three monitoring possibilities are included here, these being no monitoring of any kind, visual inspection only and monitoring of the electrical parameters of the system according to the existing analytical monitoring guidelines. In the final FMEA, different categories of electrical monitoring will be considered reflecting the analytical possibilities described earlier, particularly relating to the parameters measured and the frequency of measurement.

Table 2. Example of FMEA entry for loss mechanism for a grid-connected PV system. The Risk Priority Number is calculated from the following formula: $RPN = OI \times SI \times \text{average}(DI_1, DI_2) / 1000$. The factor of 1000 is only to provide a number that is easily interpreted and has no physical meaning. See main text for an explanation of the values provided. (NB. The values given are for illustration of the method only and should not be taken as indicative of actual field performance).

Ref. No.	Potential Cause(s) of Failure or Fault	Occurrence Notes	Occurrence Index (OI)	Potential Effects of Failure	Severity Index (SI)	Process Controls	Detection Index (DI ₁)	Diagnosis Index (DI ₂)	Risk Priority Number
1	Component failure in inverter	Most likely in first year and towards end of inverter life	20	No output from PV system	100	No inspection	100	100	200
						Visual inspection	50	70	120
						Electrical monitoring	10	30	40

The example table has an occurrence index of 20, which indicates an expectation that, on average, 20% of systems will suffer from this problem in the specified period. The occurrence notes relate to any special features of the occurrence. In this case, we would expect that the likelihood of the fault occurring would be highest in the first year of operation (due to faulty components or unsuitably high stress factors) or towards the end of life of the component. Thus, it may be useful to consider modification of the monitoring procedure to ensure more frequent checking in these periods.

In this case, the severity index is straightforward. We assume that the component failure leads to shutdown of the inverter, reducing the output of the PV system to zero. The severity index is therefore 100 (i.e. 100% of the output is lost whilst the fault continues).

The detection and diagnosis indices are separated since it is possible to observe the fault (zero system output) without being able to establish its cause. Here, the more successful the detection or diagnosis, the lower is the index, resulting in a lower Risk Priority Number when all indices are multiplied. Clearly, for no inspection of the system, the indices for detection and diagnosis are both 100. For visual inspection, it is possible to observe (from a meter or directly from the inverter) that there is no output from the system and checking of the inverter will then establish that as the problem, although there is no way of determining the factors leading up to failure. The index value depends on how often the system is checked (as it does with all forms of monitoring). For the electrical monitoring approach, detection is straightforward and easy to see from any data set, but the ability to diagnose the cause then depends on the data measured.

The final Risk Priority Number is the product of all three indices (where the detection and diagnosis indices have first been averaged to provide the monitoring index). In the example, it can be seen that comparing electrical monitoring to an approach with no system checking reduces the Risk Priority Number by a factor of 5. The full FMEA allows numerical comparison of the effectiveness of various monitoring approaches, so as to determine the most cost efficient monitoring process for a particular system. However, perhaps the most useful aspect of the FMEA is to allow comparison of the effect of various loss mechanisms, so as to identify the ones which require most attention in the monitoring process.

Clearly, the value of the occurrence index is the most difficult to estimate and is key to determining the most cost-effective monitoring process. There are two

approaches to determining the index or probability of occurrence. Probability is usually determined from the long-run relative frequency of the event occurrence, based either on theoretical or experimental considerations. In appropriate cases, reliability testing data from manufacturer tests or from a designated testing centre may also be used. In the case of faults in PV systems, the experimental or field data are obviously of most relevance in determining the value for specific faults or families of faults. This approach is empirically based and known as the frequentist approach to probability.

Secondly, there is the Bayesian approach where a subjective probability, which is a personal belief that a particular event will occur, is defined. This is usually taken to be the belief of someone with sufficient expertise for this to be a reasonable assessment. In cases, where the numerical data are insufficient to establish a probability on the basis of field measurements, it may be necessary to use subjective probabilities. In these instances, the expertise of the participants, especially those involved in commercial installations, must be used to establish reasonable starting points. The probability values can then be revised as more field data becomes available. This will need to be the practice for any future new components or technical advances in components for which little field data are available.

It is intended to derive both the severity and occurrence indices by consultation with the industry, arriving at a consensus based on confidential responses to requests to provide best estimates of the indices for different failure modes. These estimates will combine both the frequentist and Bayesian approaches as necessary.

The determination of the probability of occurrence of a fault will be necessary for each fault or, in some cases, group of faults. The simplest assumption is that the different faults are independent, i.e. that the occurrence of one fault does not make it more or less likely that a second fault would occur. Clearly, this is not actually the case with faults that are initiated or exacerbated by certain operating conditions, for example, component susceptibility to high temperatures or power surges from the grid. Allowance will need to be made for faults that are interdependent or that both depend on the same external variable. These inter-dependencies can be assessed from an understanding of fault occurrences in PV system components.

Given that reliability is a function of system type and application, as well as the detail of the individual

components, individual probability values will need to be assigned for different system categories and these can then be used to determine the level of monitoring required in each case. However, for a representative probability value, sufficient input data are required to allow for any systematic influences. Thus, there is a trade-off between the number of categories chosen and the validity of the probability value derived. As before, advice will be sought from industry before finalising the values.

6 PROGRAMME FOR IMPLEMENTATION

At the time of preparation of this paper, the initial version of the delivery package has been prepared and the detailed guidelines themselves are being constructed block by block. As has been discussed several times earlier in the paper, it is vital that the guidelines reflect both the best practice in the industry in regard to monitoring and reasonable decisions based on existing experience of probability of loss. The guidelines must also be adopted by the industry as a whole if they are to be used to their full potential in the reduction of avoidable losses in energy production of commercial systems.

An extended period of industry consultation is planned, starting with a workshop under the Performance project in late October 2008 and moving onto a testing phase with interested industry partners in the first six months of 2009. It is intended that the full guidelines in their first edition will be available at the end of 2009 when the Performance project comes to a close. Initial implementation is expected to be on the JRC web site, but the permanent site for the guidelines is still to be determined depending on the final format.

7 SUMMARY

Within the EU project PERFORMANCE, updated monitoring guidelines for PV systems are being developed. This paper has discussed the development of the first implementation of those guidelines, describing how they will address the needs of different users and system types by selecting relevant statements based on the answers to a user questionnaire. The guidelines include consideration of how monitored data can be used to detect and diagnose losses, significantly extending the information provided in current standards and guidelines.

A major factor in determining the monitoring approach, and hence the detailed guidelines, for a particular system is cost effectiveness. More intensive monitoring and analysis results in more effective recognition of avoidable losses but also generally results in higher costs. The approach to quantifying loss probabilities via a Failure Modes Effects Analysis has also been described.

The project now moves into an industry consultation phase to determine the current best practice in terms of levels of monitoring and allow this to be reflected in the finished guidelines, which are expected to be published by the end of 2009. Once available, they can be used on a voluntary basis to underpin monitoring activities and services offered by the industry and are expected to input to the updating of IEC monitoring standards.

8 ACKNOWLEDGEMENT

The PERFORMANCE Integrated Project is funded by the Sixth Framework Programme of R&D (FP6) of the European Union under contract number SES-019718. The project is co-ordinated by the Fraunhofer Institute for Solar Energy Systems, Freiburg, Germany.

The authors would like to acknowledge the contribution of the other partners in Subproject 3 of Performance for their input to the development of the guidelines, together with the members of the European PV Monitoring Expert Group convened by JRC as part of this project.

9 REFERENCES

1. Further information on the PERFORMANCE project can be found at www.pv-performance.org
2. European Photovoltaic Industries Association, "Global Market Outlook for Photovoltaics until 2012", February 2008, available from www.epia.org
3. A. Drews et al, Solar Energy, vol. 81, 2007, p.548-564
4. H. Scholz, N. M. Pearsall, T. Zdanowicz, Proc. of the 22nd European Photovoltaic Solar Energy Conference, Milan, 2007, p. 2922-2929
5. Guidelines for the Assessment of Photovoltaic Plants, Document A – Photovoltaic System Monitoring, ed. G. Blaesser and D. Munro, EUR 16338 EN, 1995
6. IEC 61724, Photovoltaic system performance monitoring – Guidelines for measurement, data exchange and analysis, IEC 1998
7. F. Vignola, P. Harlan, R. Perez and M. Kmiecik, Proceedings of the 34th ASES Annual Conference, 2005
8. Guidelines for the Assessment of Photovoltaic Plants, Document A – Analysis and Presentation of Monitoring Data, ed. G. Blaesser and D. Munro, EUR 16339 EN, 1995